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Estimating the timing of animal and plant phenophases in a boreal landscape in Northern Sweden (Västerbotten) using camera traps

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Abstract

It is becoming more important to understand shifts in plant and animal phenology as climate is changing. However, the methods to study phenology used so far have shown to be limited over time and space. Therefore, a method such as camera traps is interesting to use since it bridges satellite remote sensing and on-ground observation methods. Over 53 weeks, our cameras have recorded daily changes in plant communities and the passages of all animals across a 200 km^2 area in Västerbotten, Northern Sweden. This allowed the analysis of habitat types, plant and animal diversities and abundances, phenology as well as the changes in temperature and snow cover day after day through the software *TRAPPER*. The influence of temperature and daylength on deciduous species has been highlighted with a clear matching pattern between increasing temperatures and the onset of leaves. The presence of snow has shown to be of a greater impact for heath species. However, despite the lack of significant results for ungulates phenology, strong patterns have been assessed between the change in mountain hare coat colour and the whiteness of the landscape. The timing of such changes happened simultaneously within the same week or with more or less two weeks with week 15 (April 10^{th}-16^{th}) and week 47 (November 20^{th} -26^{th}), as breakpoint weeks showing changes in plant vegetative phenophases, shifts in both temperatures and snow cover and change in mountain hare coat colour. Whereas some shifts are easily observed such as vegetative phenophases and changes in coat colour for mountain hare, reproductive phenophases, fruit/seed phenophases for deciduous and heath types as well as vegetative phenophases for coniferous type, have been difficult to assess. However, camera traps have appeared to be a reliable tool, providing accurate data on various variables, over a long time and a broad area.

Keywords: Camera trapping, timing phenology, abiotic parameters, northern Sweden

Table of contents

1. Introduction

As climate is changing, the need of understanding shifts in plant and animal phenology is becoming greater. By definition, phenology is the study of the timing of specific biological events in plant and animal development cycles (e.g. leaf flush, migration timing) in relation to climate and season. These changes are strong indicators of the direct and indirect effects on plants and animals species from climatic changes (van Vliet *et al.*, 2003). Over the last few years, changes in precipitation regimes and temperatures patterns, as well as the increase of extreme events have caused numerous changes in the natural environment (IPCC 2014). These changes induced observable shifts in seasonal patterns and timing of phenological events such as early flowering and mismatches between environmental conditions and living organisms (Soja et al. 2007; Thackeray et al. 2016). Such shifts and mismatches can have strong impact on socio-economic aspects as well as management plans, agriculture but mostly on the overall ecosystem, leading to the eventual shifts in the whole system.

For every organisms, we can observe a phase called *phenophase* which is an " observable stage or phase in the annual life cycle of a plant or animal that can be defined by a start and end point" (Denny *et al.*, 2013). Because shifts in plant and animal phenophases have an impact on the whole ecosystem, it is essential to have greater understanding of what drives these changes and how linked to each other they are. However, the variation in the timing of phenophases is broad and complex. It can be explained by variation in temperature and precipitation but also by solar cycles and oscillations such as North Atlantic Oscillation for temperature in boreal ecosystems (Badeck et al. 2004). The visible phenological shifts can be assessed through direct observation or through images (Brown *et al.,* 2016).

Tracking and quantifying accurate timing of specific phenophases in plant and animal communities is challenging due to temporal and spatial scales. Satellite remote sensing devices have been used to observe phenology changes at the scale of land surfaces while field-based study have been recorded emphasizing on individual plant or animal observations (Rodriguez-Galiano *et al.,*2015). However, field-based studies can present more limitations. Indeed, it is expensive and difficult for a research group to collect daily data over many months, when the climatic conditions are extreme, within remote areas spread over several hundred squared kilometres by having a team in the field.

To outdo these constraints, cameras have shown to be an appropriate, high-quality and low-cost tool to use in phenological studies (Brown *et al*., 2016). Indeed, they combine the possibility to perform individual observations and to cover large areas as well as remote areas, and this at a continuous and longer time scale. Digital cameras with motion sensors, so-called camera traps, have been used increasingly to study animal ecology (Burton *et al*., 2015). Such camera traps are considered as a non invasive census method (Hofmeester *et al*. 2016) that can be used to also monitor animal species diversity, abundance, animal movement. However, as these camera traps can also be programmed to take time-lapse images, they can simultaneously be used to study abiotic parameters and phenology, including plant phenology.

Several studies highlighted the impact of changes of climatic parameters on shifts on the timing of phenological events in plant phenology and animal phenology independently (Brown *et al.,* 2016, Menzel *et al*., 2006; Parmesan *et al.,* 2003; Root *et al.,* 2003; Thackeray *et* al., 2016). In addition, citizen science increased over the last few years, allowing to collect more and more data on phenological changes by enabling the collaboration between citizen scientists with researchers, horticulturists and educators on specific-related phenological questions (Dickinson *et* al., 2012; Henderson *et al*., 2012, Newman *et al*., 2012). These collaborations allowed the science community to obtain great amounts of data and strongly influenced the advancements of phenological studies. Because the use of cameras became of a greater interest as technology improved, there is a good opportunity to use these devices as part of citizen science programs to assess phenological changes across large areas and long time periods. Nevertheless, the link between plant and animal phenology has not previously been assessed through the use of camera traps.

In this study, I therefore study phenological patterns for both plant and animal communities over the year 2017 in Northern Sweden. The aim is (1) to demonstrate that camera traps can indeed be used to study animal and plant phenology simultaneously, but also to assess (2) what is the impact of abiotic factors on the timing of shifts in plant phenology and (3) on the timing of shifts in animal phenology with the expectation to observe strong correlation between temperature, snow cover and each phenophase.

2. Methods

2.1 Study site

The study was conducted in Järnäshalvön, a 200 km² peninsula located in the Swedish county of Västerbotten. The area is characterized by boreal forests as well as mires, agricultural lands and clear cuts. It is surrounded by the Bothnian bay on three sides except on the northern side where the highway E4 as well as the towns of Nordmaling and Hörnefors are enclosing the peninsula.
In order to quantify changes in plant and animal phenology across the landscape, we used 11 hollow tracts previously equally distributed in non-urbanized habitats (1 x 1 km). Each hollow tract contained 3 cameras simultanously, all spaced by minimum 200 m from each other (Fig 1c). Each camera was located on average 50 centimeters above ground level or snow cover, preferably on a tree facing an open field of view – which is the zone covered by the camera lens - with a minimum of 15 meters open visibility. Across the year, each camera was changed every two months and replaced in the field to a next location on the hollow tract to generate 18 deployments of 2 months each (see figure 1C).

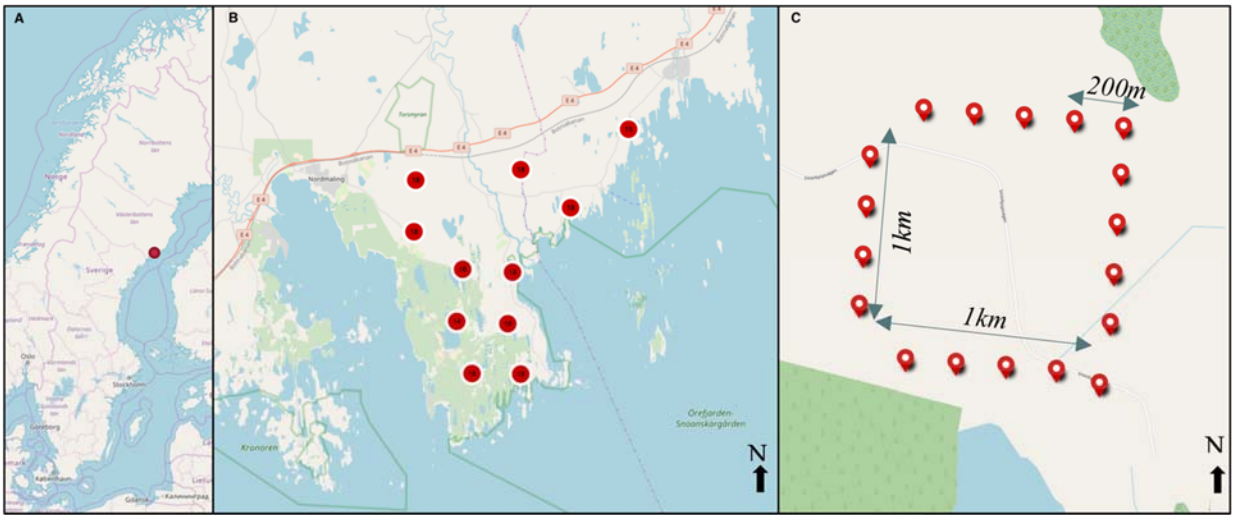

Fig 1. Study area on the Järnäshalvön peninsula (Västerbotten, northern Sweden). Elevent tracts of 1x1 km were equally placed across the peninsula (B). Each tract is composed of 18 camera deployments with a distance of 200m between each other along the four boundaries of the tract (C).

I used camera traps for three purposes: 1) to estimate, all year long, the phenological changes of plants and 2) animals while (3) obtaining both estimates and precise data on abiotic parameters such as temperature and snow cover.

The cameras used in our study are Reconyx Hyperfire HC500. They are set up to take time-laps images, every day at 12:00. Each sequence is showing the date, the time, if it’s a time-laps (T) or a movement (M) sequence and the temperature.

2.2 Image Analysis

a. TRAPPER

To extract and manage the data from the camera traps, I used *TRAPPER*. *TRAPPER* is an open source web-based application which facilitates the analysis of images with the possibility to implement spatial filtering, web-mapping and specific data collection protocols (Bubnicki et al, 2016). *TRAPPER* also favors collaborative work and a lot of flexibility in the way to treat the data by, for instance, allowing multiple classifications of single resources (Fig 2).

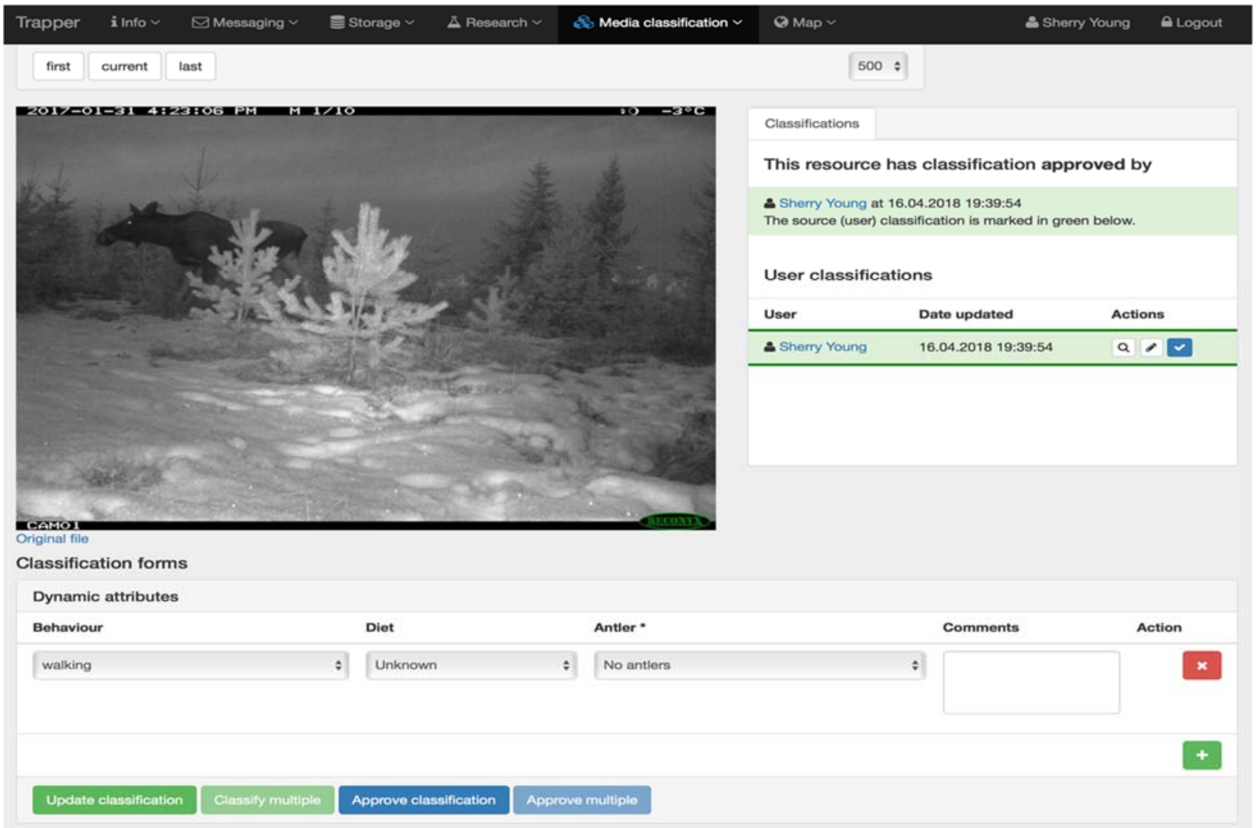

Fig 2. TRAPPER data base with an example of ungulate phenology classification.

b. *Data organization*

The data was collected over 12 months and 2 weeks, from the 29th of January 2017 to the 14th of February 2018. The data was then segregated in three main projects: timelaps images for plant phenology, timelaps images for weather data and movement-triggered images for animal phenology. All sequences which were not fitting the pre-requirements of our methods were removed (e.g snow or ice covering the camera; movement sequences type due to vegetation in front of sensor). For each of the previously mentioned projects, classification sub-projects were created in order to study plant and animal phenology once the species were assessed. For each of the subset, a list of attributes, corresponding to the *phenophase status*, was used to describe the potential observations made on each sequences, either for the “movement” or “time-laps”. The phenophase status were used from the standardized phenology monitoring methods from the USA National Phenology Network (Denny *et al*., 2013) which allows to obtain standardized monitoring protocols across ecosystem types and taxonomic groups. Concerning the study of plant phenology, three groups of phenophases were made: “Vegetative phenophases” (Tab 1), “Reproductive phenophases” (Orange, Tab 1), and “Fruit/Seed phenophases” (Red, Tab 1).

*Table 1. Used animal and plant phenophases status with, for plants, vegetative phenophases (green), reproductive phenophases (orange) and fruit/seed phenophases (red). The phenophase status with a * are not part of the standardized phenology monitoring method created by the USA-NPN but added by our team and the phenophases in bold are the ones we statistically tested.The lack of data on the other parameters did not allow the statistical analysis.*

Phenophases status

Animal	**Plants**		
Active individuals	**Initial growth**	**Flowers or flower buds**	**Fruits**
Feeding	**Breaking leaf buds**	Open flowers	Ripe fruits
Mating	**Young leaves**	Pollen release	Recent fruit or seed drop
Young individuals	Increasing leaf size	Pollen cones	Unripe seed cones
Summer coat (Brown*)	**Colored leaves**	Open pollen cones	Ripe seed cones
Winter coat (White*)	**Fallen leaves**		Recent cone or seed drop
Sex*	**Leaves**		
Growth of antlers*	Emerging needles		
Antlers*	**Young needles**		
Sub-Adults*	**Needles**		
Adults*	**Colored needles**		
Vigilant*			
Curious towards camera*			
Grooming*			
Flight*			

c. *Time-lapses images*

Each digital camera was triggered at 12:00. Time-laps images were then analized for each deployment. In a first round, the images were classified between “Control”, “Gap”, if the images could not allow the analysis of phenology due to change in camera position over time or snow covering the camera , and “Corrupted File” if the images could not be properly read. Daily temperature sampled by each device as well as estimates of snow cover were recorded simultaneously. In this case, snow cover estimates were linked to food availability. Therefore, only the snow cover on the ground was estimated and not the overall whiteness of the landscape. Then, for each deployment, the images were sequenced per week number and for each sequence, plant species were recorded, using a list (Appendix 1) made in the same area from a field-based-observation study (Spitzer, Personnal Communication, 2017). For each plant species, I recorded the “percentage of greenness”, “percentage of cover” and “Phenophases”, resulting in one observation per week per species. Moreover, from the time-laps images, the habitat types were recorded for each location and aggregated per tract. The habitat types were segregated in 9 categories named after the most dominant tree species: Alder, Birch, Birch-Spruce, Mixed (more than three tree observed species), Pine, Pine-Birch, Pine-Spruce, Pine-Spruce-Birch, Spruce at each location. In addition, the habitat types included two categories: Edge and Clear-Cut. I used the Braun-Blanquet Method to estimate both percentages of snow and plant species cover (Wikum & Shanholtzer, 1978).

d. *Movement images*

Each sequence clustered the images recorded within less than 5 minutes in between. At first, each sequence was classified as “Set Up / Pick Up” for the images showing the research team setting up or picking up the cameras, “Animal” if an animal was observed, “Human” if a human was observed, “Empty” if no individual was observed, or “Corrupted File”. If an animal triggered the camera, the “Species” name was annotated as well as the “Number of individuals”, if any of the individuals was “Collared” if the animal had a GPS collar, the “Sex” of the individuals and their “Age”, differentiating between “Juvenile”, “Sub-Adult” and “Adult” if observable through body size and physical characteristics, mainly for ungulate species. A list of species expected to be seen in the area was made and imported in *TRAPPER* for the data extraction (Appendix 1). Within one sequence, each image was annotated depending on the number of individuals and the observed species, giving one observation per sequence per species. Once this step done, each sequence was annotated again for ungulates species – roe deer (*Capreolus capreolus*), red deer (*Cervus elaphus), fallow deer (Dama dama*) and moose (*Alces alces*) – and mountain hare (*Lepus timidus*). At last, the antlers and their growth stage were annotated, dividing the phenophases between "Growing antlers (skin)", "Antlers (no skin)", "No antlers" and "Unknown".

Concerning the mountain hare, the "Whiteness of hare" was extracted by differentiating between "White" (coat > 90% white), "Brown" (coat > 90% brown) and "Moulting" hare. If "Moulting", the percentage of moulting was recorded by visually estimating what percentage of the coat was white. The landscape whiteness was also recorded, including the whiteness of the stand and not only the ground snow cover as tested previously. To estimate the landscape whiteness, the Braun-Blanquet method was also used since this method is helpful regarding obtaining better visual estimates. Then was assessed the correlation between landscape whiteness and whiteness of coat colour of the mountain hare.

2.3 Statistical analysis

Statistical analyses were performed with R Studio (R Core Team, 2017). The normality of the residuals from the data distribution was assessed by Shapiro-Wilk normality test for the numerical variables and Kolmogorov-Smirnov for the categorical variables. I used linear regression and two-way analysis of variance (ANOVA) with Tukey's HSD post-hoc comparisons to investigate potential homogeneity of the area by testing differences in plant and animal abundances between tracts if variables and their residuals follow normal distribution after transformation. If the variables did not follow normal distribution, I used a non-parametric alternative to ANOVA – the Kruskal-Wallis test.

Concerning the study of shifts in plant and animal phenophases, I grouped the plant species within four vegetation types: Heath (*Vaccinium sp, Calluna sp*), Deciduous (*Betula pubescens*, *Sorbus commixta*, *Populus tremula*, *Alnus glutinosa*, *Salix sp*, *Rubus sp)*, Coniferous (*Pinus sylvestris*, *Picea abies*, *Juniperus communis*) and MGFLH (Moss, Grass, Forbs, Lycopods and Horsetail). I transformed the data to a binomial format and calculated the weekly ratio of the presence of each phenophase for each location. The weekly phenophases ratios were calculated in relation to the presence of the other phenophases within each vegetation type across all tracts. The impacts of the weekly mean temperatures, estimates of snow cover, and day length were assessed through the use of standardized binomial logistic regression. Also, I calculated the differences between each weekly temperature, snow cover and daylength values in order to test if these trends were influencing the shifts in plant phenophases. The study of the MGFLH (Moss, Grass, Forbs, Lycopodes and Horsetails), was not pursued due to the lack of data in order to study the shifts in phenology. All statistical tests use a significance level of 5% ($\alpha = 0.05$).

Results

3.1 Changes in abiotic parameters and evaluating the efficiency of camera traps

a. Abiotic factors

Trends in temperatures and snow cover estimates were tested at first. The daily temperatures and snow cover have coherent variation across the year compared to previous years data (SMHI, 2017). As the temperatures increased week 12, the snow cover decreased between week 17 (April 24th-30th) and 19 (May 8th-14th). The increase of snow cover happened week 47 (November 20th -26th), six weeks after the temperatures were reaching 0°C. Due to these breakpoints, I delimited the seasons with winter from week 47 (November 20th-26th) until 15 (April 9th-15th), spring between week 15 and 22 (May 28th- June 3rd), summer between week 22 and 35 (August 27th – September 2nd) and fall until week 47.The minimum weekly mean temperature is -24°C and the maximum weekly mean temperature is 31°C.

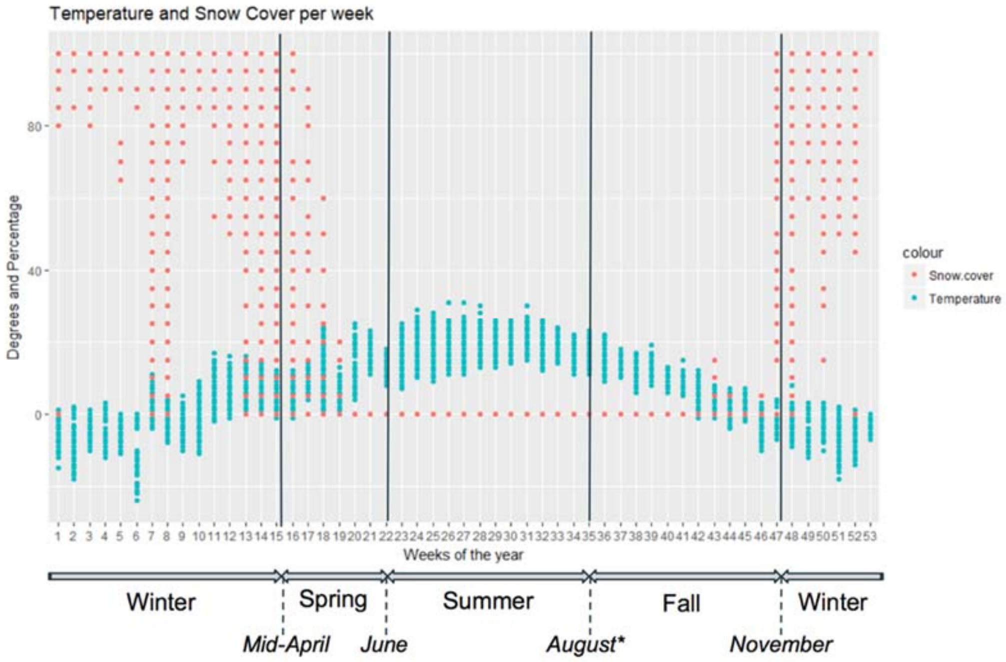

Fig. 3 Weekly average of snow cover and temperature over the peninsula between the 29th of January 2017 and the 14th of February 2018 with delimitation of the seasons depending on the occurrence of shifts in temperature and snow cover. Each dot is a weekly average per site/camera.

A climatic gradient between the tracts located closer to the Baltic sea and the ones near the highway E4 was expected but by testing through a One Way-Anova between tracts, it appeared that there was no significant difference in the temperature and snow cover between sites and week during the year (F-value: 0.31, df: 52).

b. *Habitat types*

In order to obtain a greater understanding of the study area, the potential differences in habitat type compositions of each tract were tested. The tracts located across the peninsula presented differences in their habitat types heterogeneity. For instance, tracts number 40, 49, 56 and 62 had between two to three more habitat types than the other tracts (Fig. 4). Land use in these areas were highlighted by the presence of clear cuts in 10 out of 11 tracts. The two northernmost tracts were characterized by mixed deciduous forest. However, there was no significant difference between tracts in habitat type composition after testing through Kruskal-Wallis test (p-value = 0.47).

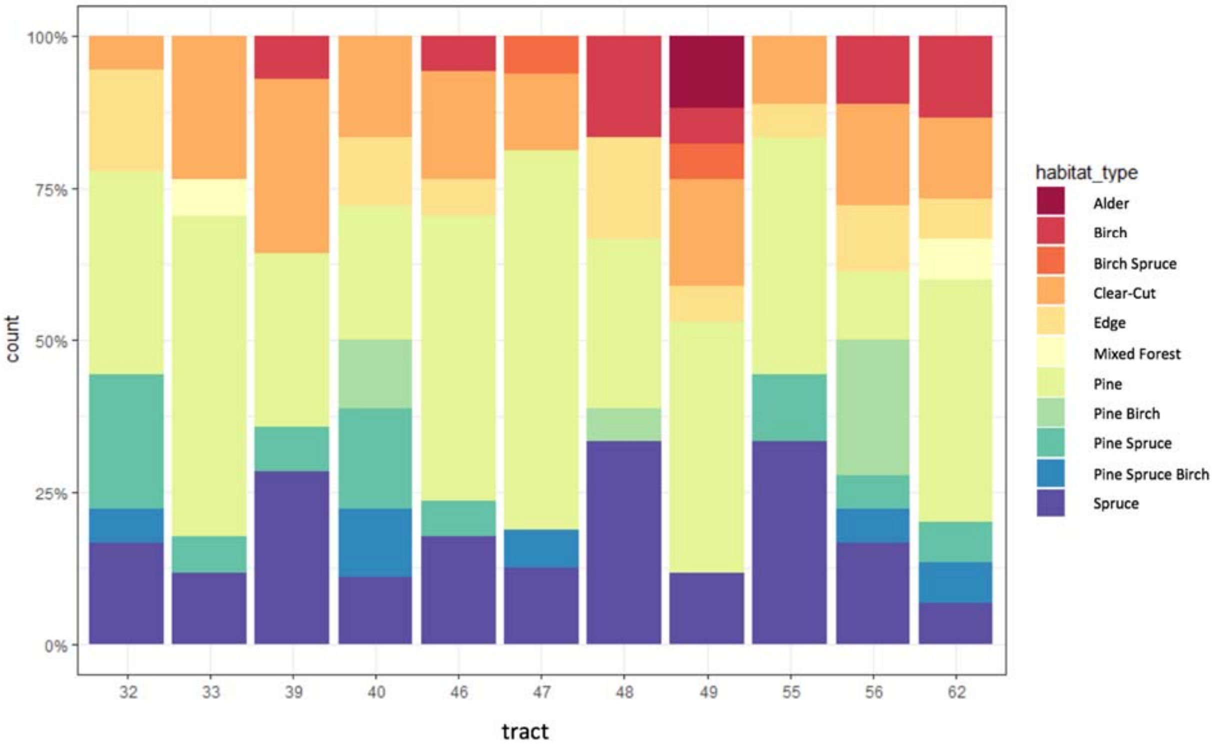

Fig 4. Habitat types composition for each tract, here annotated from South to North (respectively 32,33,39,40,46,47,48,49,55,56,62).

Because there was no apparent climatic gradient and no significant differences in habitat types between tracts, the study of phenology was tested regardless of the locations, considering the peninsula as an homogeneous environment.

3.2 Changes in biotic parameters (plant and animal phenology)

a. What is the impact of abiotic parameters on shifts in plant phenophases?

As mentioned previously, the weekly mean values of snow cover estimates as well as temperature had contrary patterns with a decrease of snow cover around week 17. A strong decrease in week 7 of snow cover was consistent with a higher temperature the same week (Fig 5. A and B). The correlation between daylength and temperature can be observed as well as the fact that there is more variation in temperature in the spring than in the fall (Fig 5. B and C).

For both deciduous and heath types vegetative phenophases, the increase of the amount of leaves with, in the meantime, the detection of leaf buds and young leaves followed the expected chronological patterns (Fig 5).

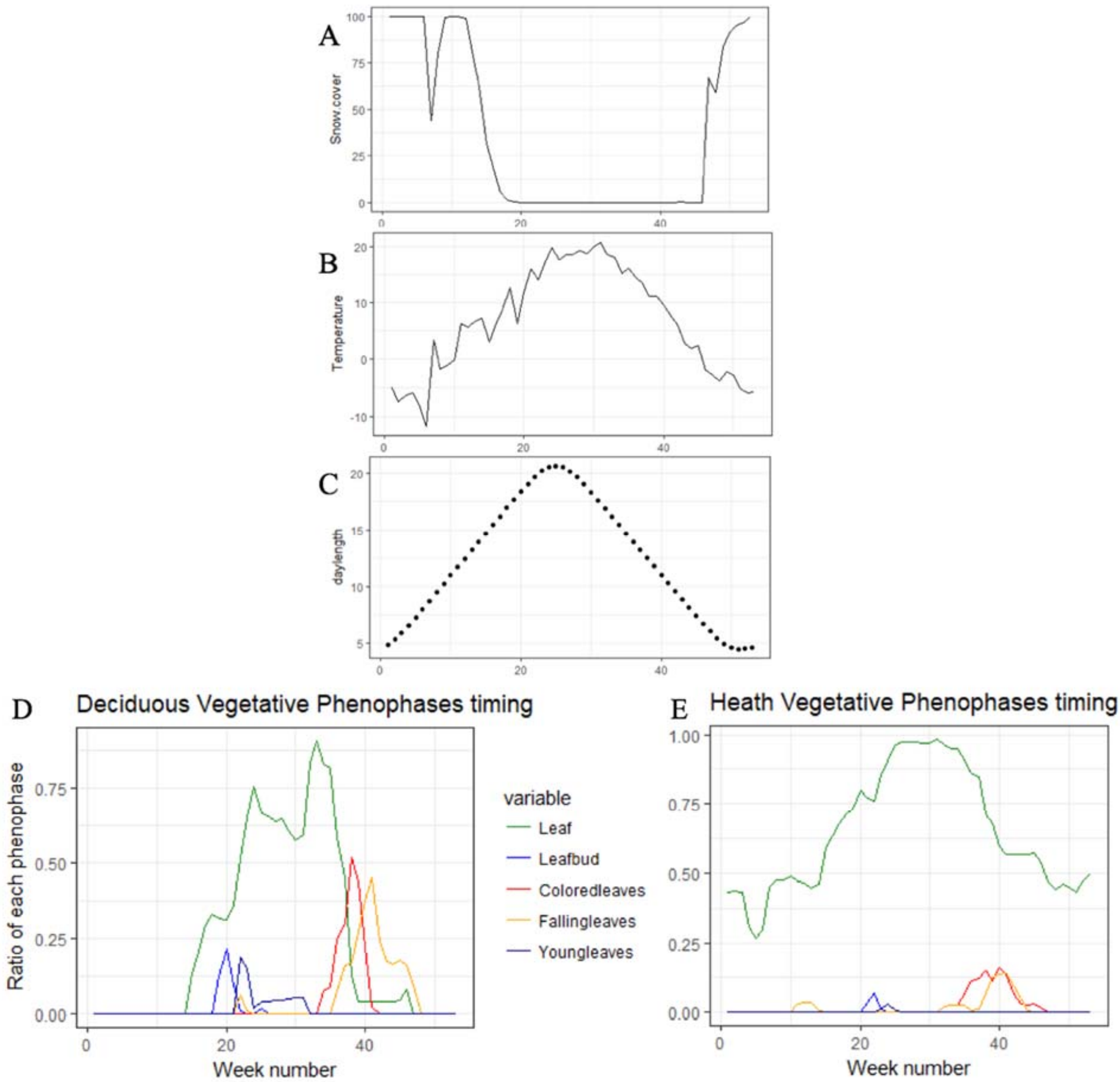

Fig 5. Weekly average of snow cover (%) (A) and temperature (Celcius Degrees) (B) over the peninsula between the 29th of January 2017 and the 14th of February 2018, so 53 weeks. Weekly average daylengths (C) and ratios of each vegetative phenophase present at all sites for deciduous vegetation type (D) and heath vegetation type (E).

For deciduous species, the increase of the presence of leaf buds was later, week 19 (May 8th – 14th) than the first detected leaves week 15 (April 10th-16th), due to the difficulty to observe the apparition of the buds (Fig 5. D). However, leaf bud timing was prior to the recording of young leaves which was coherent and fitting our expectations. Similar patterns have been observed with the phenophases related to senescence. Colored leaves were detected week 34 (August 21st – 27th) and started falling two weeks later. The same observation was made for deciduous species with an increase of the presence of leaves between week 15 (April 10th-16th) and week 46 (November 13th-19th) (Fig 5. E, Appendix 2). It appeared that temperature and daylength were the main factors impacting the presence of leaves throughout the year for both vegetation types, with snow cover having a slight significant influence on leaves for the heath vegetation type (Appendix 3). However, we did not obtain any significant correlation between the abiotic parameters with the other vegetative phenophases.

Only the heath vegetation types have shown patterns for reproductive and fruit/seed vegetative phenophases. Flowers became apearent in week 23 (June 5th – 11th) and disappeared in week 47. Fruits and ripe fruits were first observed in week 25 (June 19th-25th) and also ended in week 47. However, there was no significant impact neither from the abiotic parameters nor their trends on the timing of the different reproductive and fruit phenophases.

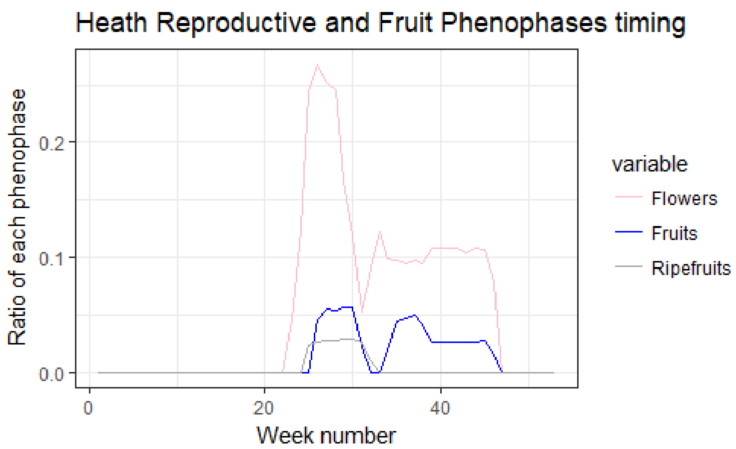

Fig 6. Weekly averaged ratios of each reproductive and fruit phenophase present at all sites for heath vegetation type.

However, the phenology of coniferous vegetation type did not show any pattern in the timing of the phenophases.

b. What is the impact of abiotic factors on shifts in mountain hare phenology?

At first, a mismatch between the coat colour and the environment is visible without performing any statistical analysis. (Fig 7).

Fig 7. Images extracted from digital cameras in Järnäshalvön from May, showing a mismatch between coat colour and the environment of the mountain hare.

The whiteness of the landscape starts decreasing in week 15 (April 10th – 16th) and we can observe a slight delay in decrease of the whiteness of the coat which happens between one and three weeks later (Fig. 8). The hares became brown in week 25 (June 19th – 25th) and stayed brown until week 40 (October 2nd – 8th) where the coat started moulting. However, the landscape became whiter in week 47 (November 20th – 26th), creating a mismatch with the timing when mountain hares were recorded white as well (Fig. 8).

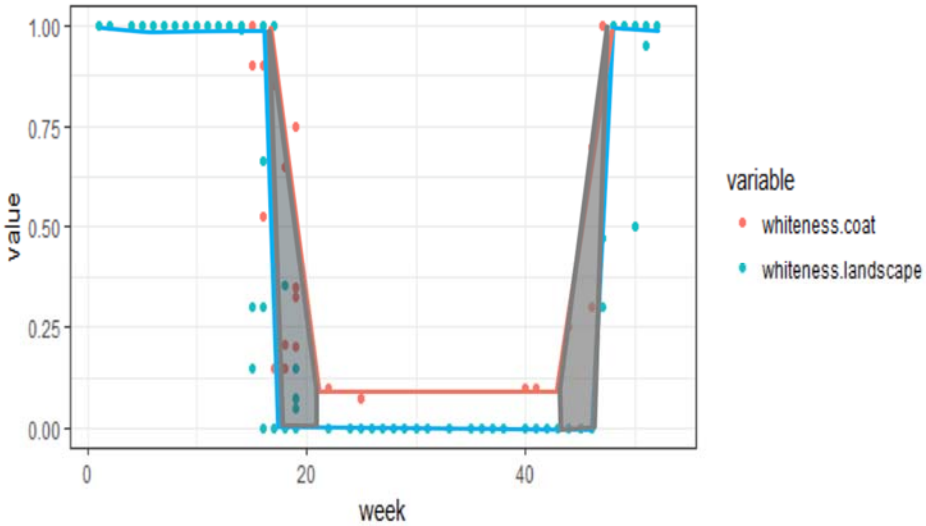

Fig 8. Correlation between mountain hare whiteness and whiteness of the landscape per week. Each point is an average ratio in whiteness per week, averaged over all observations. The grey areas highlight the mismatch between the observed change in whiteness of the landscape and whiteness of the mountain hare coat color.

By testing the influence of temperature and whiteness of the landscape on whiteness of the coat, the results highlighted that both abiotic parameters have a strongly significant impact on the whiteness of the coat of the mountain hare (Tab. 3).

Table 3. Summary of the binomial logistic regression estimates and their significance level for the relation between each abiotic parameters on the coat whiteness of the mountain hare.

Phenophases	**Abiotic parameters**	**Estimates**	**p-value**
Coat whiteness	Temperature	-0.2877	**8.96e-08*****
	Snow	11.4122	**0.00278****

c. *What is the impact of abiotic factors on shifts in ungulates phenology?*

On average antler growth is either induced in week 15 (Fig 9. D) or increasing this same week (Fig 9. A, C). Moose have the antler growth starting a couple of weeks later. However, testing the influence of snow cover and temperature on the growth of the antlers did not show any significant result (Appendix 4).

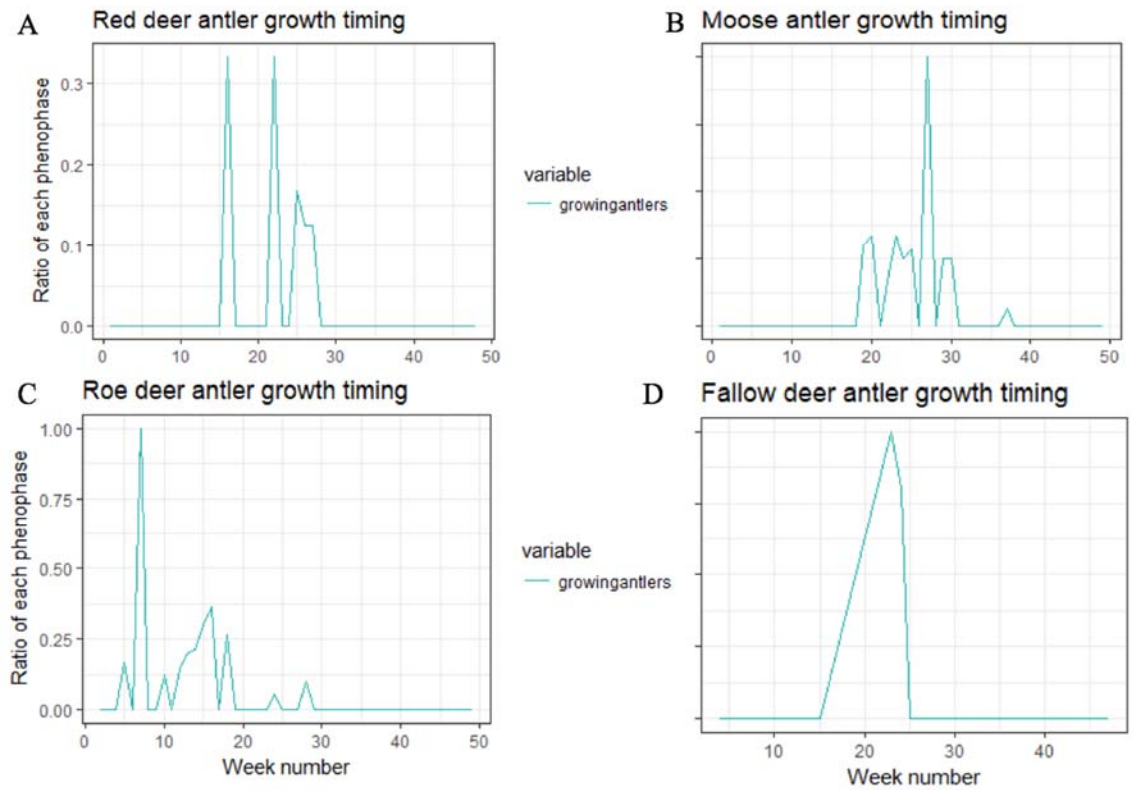

Fig 9. Timing of the antler growth period for (A) Red deer (Cervus elaphus), (B) Moose (Alces alces), (C) Roe deer (Capreolus capreolus) and (D) Fallow deer (Dama dama).

Discussion

The results obtained in this study outline several patterns which assess the impact of abiotic factors on plant and animal phenology. Phenology has mainly been assessed for deciduous and heath vegetation types due to easier observable seasonality, despite the presence of evergreen species as part of the heath group. The timing of leaf phenophase was triggered by temperature and daylength which is concordant with previous findings showing that photoperiod and temperatures mediate the onset of leaves (Polgar & Primack, 2011). However, the apparition of leaves in the heath group type has shown to mainly be correlated to snow cover, showing the species-specific sensitivity in phenology (Torp, 2010; Bater *et al.*, 2011). Nevertheless, neither abiotic parameters nor the trend – the in-between weekly differences in temperature, snow cover and daylength - had a statiscally significant impact on other vegetative phenophases, as well as for reproductive and fruit/seed phenophases. This is explained by a lack of data resulting from a more difficult assessment of several phenophases due to resolution limitations. Moreover, the heath group contains evergreen species such as *Vaccinium vitis-idea* and also *Vaccinium myrtillus* which is deciduous, biasing some results, like showing the presence of leaves all year long which is not supposed to be observed for deciduous species.

Concerning the ungulates, temperature and snow did not seem to directly impact the timing of the changes in phenophases status for the growth of the antlers even though, as soon as temperatures increased, the growth was seen to be induced in the following weeks. However, the analysis was run for both males and females, making the results discussable even though we can still observe the timing of the antlers growth. However, the result are concordant with the fact that previous studies have shown that antler growth is mainly triggered by increasing testosterone, induced by increasing photoperiod (Pierce II *et* al. 2012). For the mountain hare phenology, both temperature and snow did have a strong influence on the changes in whiteness of the mountain hare coat (Mills *et al*. 2013; Pedersen *et al*. 2017). Despite the fact that the changes are influenced by different abiotic factors, the timing of these shifts were overall mostly happening at the same weeks or in the same range. Indeed, during week 15 and week 47, the main changes were observed such as changes in temperatures, start of antler growth, mountain hare moulting or the increase of the presence of leaves.

My results confirmed that camera traps are accurate tools to understand changes in phenology for large mammals and plant species such as species included in deciduous and heath vegetation types. However, coniferous, moss/grass/forbs/lycopodes and horsetail (MGFLH) phenology were difficult to assess due to the resolution of the cameras and therefore not presented in this study because of a lack of data. Nevertheless, camera traps provide accurate data on a wide range of variables such as temperature, snow cover, habitat types, plant and animal phenology as well as animal and plant diversities, abundances over a long time and a large area. There is also a possibility to record mountain hare and ungulates diet, as well as their behavior which is also considered as a phenophases according the USA-NPN phenophases definition but not presented in this study. The importance of camera traps and the assessment of phenological changes in plants and mammal is also highlighted by the increasing possibility to have citizen science using such devices in addition of the scientific community. It provides a real potential to obtain a wider and more continuous understanding over time of phenological patterns and timing (Gonsamo *et al*. 2013; Morisette *et al*., 2009; van der Kolk *et al.*, 2016).

To conclude, by using this method over a longer time period, changes in plant phenology and animal phenology will be more easily assessed and allow the scientific world to gain a better understanding of phenological timing and therefore the impact on the ecosystem. This study highlighted the current limitations of the use of camera traps for plant and animal phenology due to resolution. While the devices are being improved in order to detect changes at a smaller resolution, it is important for the scientific community to develop . However, estimating changes in plant and animal phenology by the use of camera trapping over a large scale and a long time period is possible and accurate.

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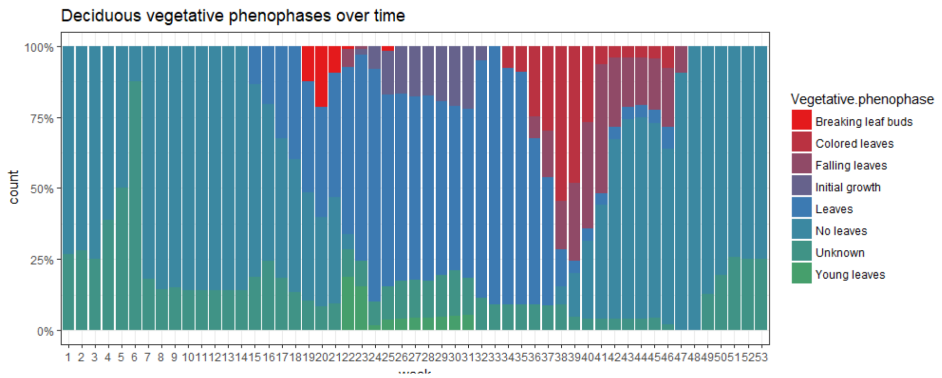
Appendix 1

*Table. Used animal and plant lists for analysis. The species names with * were added after analysis because triggered by the camera.*

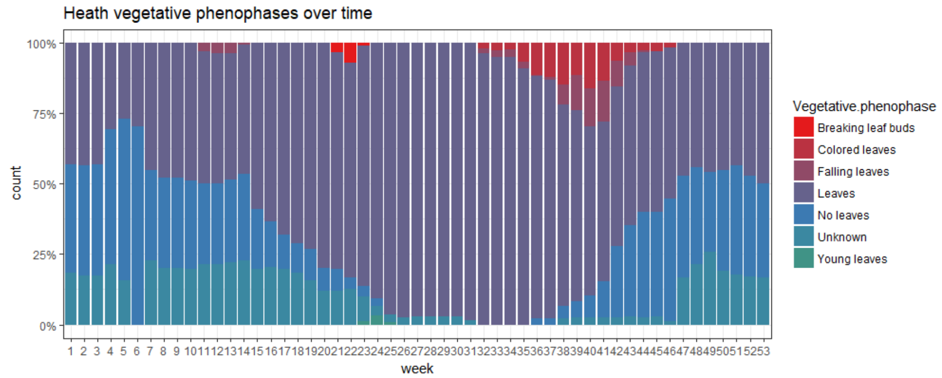
Species list

Animal	Plant
Willow ptarmigan (*Lagopus lagopus*)	Spruce (*Picea abies*)
Hazel grouse (*Tetrastes bonasia*)	Pine (*Pinus sylvestris*)
Black grouse (*Lyrurus tetrix*)	Birch (*Betula pubescens*)
Capercaillie (*Tetrao urogallus*)	Rowan (*Sorbus commixta*)
Crane (*Grus grus*)	Aspen (*Populus tremula*)
Thrushes (*Turdus philomenos*)	Alder (*Alnus glutinosa*)
Badger (*Meles meles*)	Salix (*Salix sp*)
Fallow deer (*Dama dama*)	Bilberry (*Vaccinium myrtillus*)
Moose (*Alces alces*)	Lingon (*Vaccinium vitis-idea*)
Mountain hare *(Lepus timidus*)	Calluna (*Calluna vulgaris*)
Red deer (*Cervus elaphus*)	Juniper (*Juniperus communis*)
Red fox (*Vulpes vulpes*)	Raspberry (*Rubus idaeus*)
Roe deer (*Capreolus capreolus*)	Labrador tea (*Rhododendron sp.*)
Least weasel (*Mustela nivalis*)	Graminoid – Cypreceae
Small mammals	Graminoid – Juncucae
Stoat (*Mustela erminea*)	Graminoid – Poaceae
Pine marten (*Martes martes*)	Forbs
Red squirrel (*Sciurus vulgaris*)	Ferns, Lycopods, Horsetail (FLH)
Bear (*Ursus arctos*)	Other vegetation type (lichen, moss, fungi)
=Lynx* (*Lynx lynx*)	

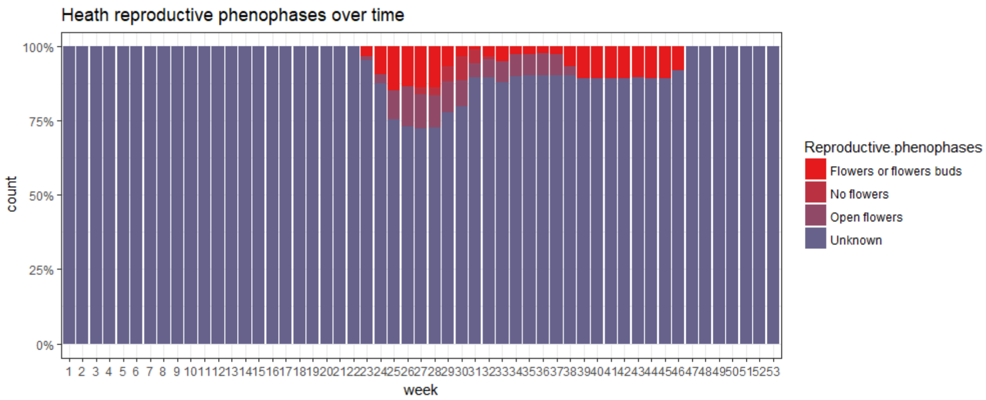
Appendix 2



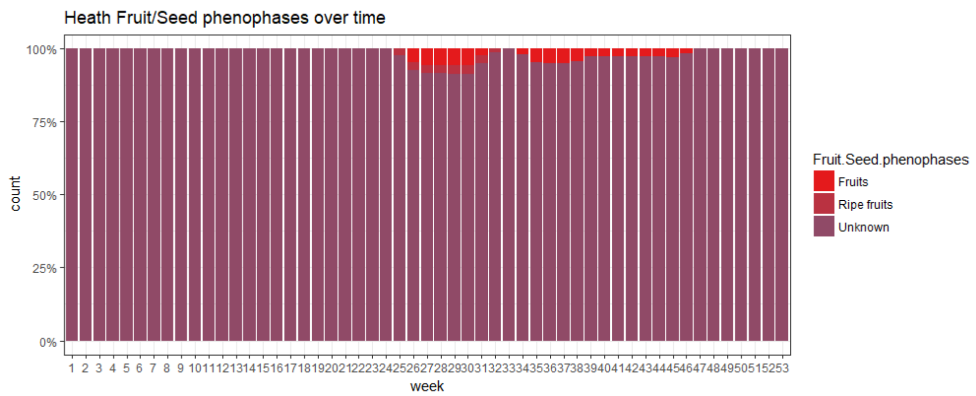
A: Changes in vegetative phenophases in deciduous species per week.



B: Changes in vegetative phenophases in heath species per week.



C: Changes in reproductive phenophases in heath species per week.



D: Changes in fruit/seedphenophases in heath species per week.

Appendix 3

Table. Summary of the binomial logistic regression estimates, standard error and their significance value for the relation between each abiotic parameters on both deciduous and heath vegetative phenophases with "d." meaning difference.

Phenophase	**Abiotic parameters**	**Deciduous**			**Heath Type**		
		Estimate	Std Error	p-value	Estimate	Std Error	p-value
Leaf	Temperature d.	0.033	0.101	0.743	0.030	0.096	0.752
	Snow cover d.	-0.005	0.021	0.812	-0.002	0.019	0.901
	Daylength d.	-6.244	3.706	0.092	-4.679	3.220	0.146
	Temperature	**0.259**	**0.079**	**0.001**	**0.113**	**0.039**	**0.004**
	Snow cover	-0.080	0.062	0.197	**-0.017**	**0.007**	**0.013**
	Daylength	**0.353**	**0.107**	**0**	**0.164**	**0.063**	**0.009**
Leafbud	Temperature d.	0.137	0.354	0.699	0.0316	0.035	0.972
	Snow cover d.	-0.001	0.099	0.999	-0.0001	0.198	0.999
	Daylength d.	24.278	57.171	0.671	14.629	60.701	0.810
	Temperature	0.062	0.181	0.731	0.104	0.421	0.804
	Snow cover	-0.257	2.184	0.906	-184.144	7594.43	0.9807
	Daylength	0.006	0.181	0.731	0.604	2.025	0.766
Colored leaves	Temperature difference	-0.175	0.297	0.555	-0.175	0.390	0.653
	Snow cover d.	-0.0002	0.049	0.997	-0.0001	0.065	0.998
	Daylength d.	-289.70	470.76	0.538	-230.91	515.52	0.654
	Temperature	0.075	0.093	0.421	0.06	0.117	0.605
	Snow cover	-178.67	6336.17	0.977	-3.975	33.76	0.906
	Daylength	0.011	0.138	0.936	-0.016	0.183	0.932
Young leaves	Temperature difference	0.048	0.356	0.892	0.166	0.986	0.866
	Snow cover d.	-0.0002	0.081	0.998	-0.0001	0.297	1
	Daylength d.	0.403	13.186	0.976	4.419	52.06	0.932
	Temperature	0.235	0.325	0.468	0.265	1.342	0.844
	Snow cover	-160.19	6342.22	0.979	-164.024	7585.251	0.983
	Daylength	0.663	0.910	0.466	3.232	19.077	0.865
Initial	Temperature difference	0.057	0.243	0.813	-4.4e-15	1.6e04	1
	Snow cover d.	-0.0001	0.056	0.997	0	3290.41	1
	Daylength d.	-9.449	12.127	0.436	-5.3e-14	5.3e05	1
	Temperature	0.6133	0.587	0.296	-1.1	5.4e03	1
	Snow cover	-173.70	6359.24	0.978	-9.5e-18	1.2e03	1
	Daylength	0.533	0.487	0.274	1.5e-15	9.2e03	1

Appendix 4

Table. Summary of the binomial logistic regression estimates, standard error and their significance value for the relation between each abiotic parameters and antler growth (antlers growth), presence of antlers (antlers without skin) and the absence of antlers per species.

Phenophase	**Abiotic parameters**	**Roe deer**			**Red deer**		
		Estimate	Std Error	p-value	Estimate	Std Error	p-value
Antlers	Temperature	0.055	0.045	0.225	-0.024	0.043	0.580
	Snow cover	-0.015	0.012	0.241	0.002	0.009	0.807
Growing antlers	Temperature	-0.096	0.083	0.251	0.130	0.170	0.446
	Snow cover	0.014	0.014	0.330	-0.297	1.464	0.839
No antlers	Temperature	-0.035	0.039	0.362	0.003	0.037	0.927
	Snow cover	0.010	0.009	0.278	0.006	0.009	0.519
		Fallow deer			**Moose**		
		Estimate	Std Error	p-value	Estimate	Std Error	p-value
Antlers	Temperature	0.033	0.069	0.637	-0.052	0.054	0.339
	Snow cover	-0.019	0.024	0.428	-0.007	0.015	0.614
Growing antlers	Temperature	0.399	0.300	0.185	0.255	0.166	0.124
	Snow cover	-6.310	1814.943	0.998	-68.017	7391.987	0.993
No antlers	Temperature	-0.070	0.060	0.240	0.001	0.039	0.988
	Snow cover	0.014	0.016	0.396	0.009	0.010	0.375

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